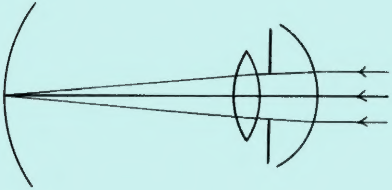
THINGS of science



VISION

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VISION

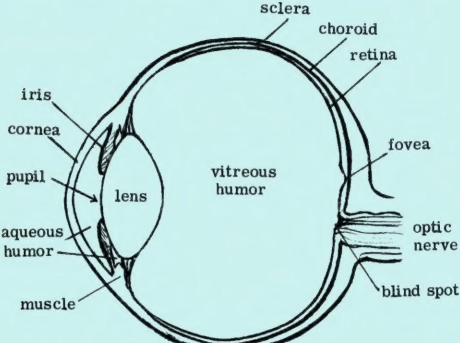
The eye, one of nature's miracles, is a complex instrument, consisting of millions of tiny parts that bring the visual world to our consciousness. It is made up essentially of the iris, lens, a light-tight cavity and the retina on which the outside images are focused and from which messages are sent to the brain for interpretation of what is seen.

The eyeball is slightly egg-shaped and is protected by a tough outer coat called the sclera (Fig. 1). The sclera is white and opaque and forms the "white of the eye." At the front of the eye, the sclera blends with the cornea, a transparent tissue that bulges a little outward.

The cornea protects the front of the eye and also acts as a lens to bend the light toward the center of the eye.

The circular area just behind the cornea that gives the distinctive color to a person's eye is the iris. It serves as a diaphragm to control the size of the black central area, the pupil. The pupil is actually a hole. It looks black because there is almost no light coming out of it. It is through this hole that the light rays enter the eye and strike the retina. The pupil responds to the amount of light

passing through it. It becomes smaller, or constricts, when illumination is increased and widens, or dilates, when it is decreased.



Horizontal section of the right eye.

Fig. 1

Just behind the iris is the lens, clear and transparent. The lens is held in place by muscles, the suspensory ligaments attached along the outer edge of the lens and the ciliary muscle encircling the lens.

The space between the iris, lens and cornea, the anterior chamber, is filled with a watery fluid known as the aqueous humor as is also the posterior chamber, the space behind the iris and in front of

the muscles.

In back of the lens is the large light-tight cavity, composing the greater part of the eyeball, filled with a transparent gelatinous substance, the vitreous humor.

The wall of the eye consists of three layers: the outer sclerotic coat; the choroid layer in the middle containing a brownish black pigment that absorbs any stray light; and the retina, the innermost layer.

The retina is the seeing part of the eye and contains millions of cells known as rods and cones. The rods and cones, so-called because of their shapes, are the receptors responsible for vision.

The retina is composed of three distinct layers.

The rods and cones are located in the layer of the retina closest to the choroid. The axons, or nerve fibers, extending from the rods and cones make connections with nerve cells or neurons in the middle layer of the retina. The axons of these neurons carry messages to the ganglion cells in the third and innermost layer of the retina. The axons from the ganglion cells form a large nerve trunk consisting of about one million fibers and leave the retina at the back of the eye. The bundle of axons together comprise the optic nerve

which leads to the brain.

The point at which the optic nerve leaves the eye is known as the blind spot. It is devoid of rods and cones and thus no visual reception occurs there.

Opposite the lens and on the posterior wall of the retina is found a yellow circular area called the macula lutea. In the center of the macula lutea is a small area called the fovea centralis containing only cones. The clearest image is obtained when an object is focused on this part of the retina.

The cones, of which the eye has some ten million, have a relatively high threshold of sensitivity to light and are concerned with day vision. They are also responsible for our ability to see color.

The area surrounding the fovea centralis contains mostly rods—more than 100 million of them. The rods are much more sensitive to light than the cones and provide us with vision in dim light or night vision.

Light received by the eyes can vary in many ways, such as intensity, wavelength and in the pattern of distribution over the retina.

Our eyes are not made to respond to all of the various changes that occur in

illumination. For example, we usually do not detect the direction of the polarization of light, but we can sense different degrees of light intensity, changes in wavelength that produce color and the shapes of objects.

Most important, however, is the ability of our eyes to adjust to different conditions so that we may receive the greatest amount of information over a wide range of light intensity, from dim starlight to bright sunlight.

The experiments in this unit will help you understand how we see and you will also observe some of the tricks our eyes can play upon us.

First look over your specimens.

BICONVEX LENS—Plastic lens with both surfaces curved outward; ¾ inch in diameter.

CONCAVE LENS—Plastic lens with both sides curved inward; ½ inch in diameter.

BLACK PAPER—One sheet.

COLORED PAPERS—One each of blue, red and green.

DIAGRAM SHEET—Folded sheet containing various diagrams.

LENS HOLDERS—Two; one for convex lens and one for concave lens.

OPTICAL PROPERTIES

The cornea, aqueous humor and vitreous humor all have a part in focusing an image on the retina. The lens, however, is the active participant, becoming thicker or thinner as we view an object close by or at a distance.

Experiment 1. Examine the larger lens in your unit. Note that both surfaces are curved outward and that the lens is thicker in the center than at the edges. A lens of this type having equal curvatures on each side is called a biconvex lens.

The lens of the eye is shaped somewhat like your biconvex lens. However, it is more sharply curved on the inside surface than at the front (Fig. 1). It is about one-half inch across and one-fourth inch in thickness when at rest.

When light travels from one medium into another of a greater or lesser density, it is bent or refracted.

Experiment 2. Place a pencil in a glass of water and view it from the side through the glass. The pencil appears bent where it enters the water. This is because the light rays pass from the less dense air into the more dense water.

When light passes through a convex lens from the air (from a rarer medium

to a denser medium and again into a rarer medium) the rays are bent toward the thicker portion of the lens as they emerge. The rays converge and meet at a single point, the focal point. A convex lens is therefore referred to as a converging lens.

When the source of light is at an infinite distance, the rays striking the lens will be parallel. Parallel rays passing through a convex lens meet at a point known as the principal focus of the lens or its focal point (P in Fig. 2).

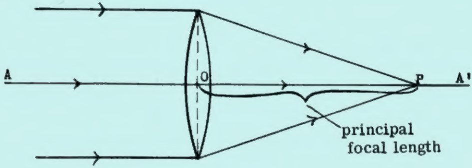


Fig. 2

The line AA′ (Fig. 2) which passes through the center of the lens and through the principal focus is known as the principal axis. The distance from the center of the lens O to the focal point P is the principal focal length.

Insert your convex lens in the lens holder with the larger hole.

Experiment 3. You can find the principal focal length of your convex lens by focusing the image of the sun on a cement walk or other nonflammable surface. When the light rays from the sun converge to a single bright point, measure the distance from the image to the center of the lens. You will find that the focal length (image distance) of your lens is about $1\frac{7}{8}$ inches.

The focal length of a lens depends upon the curvature of its surfaces. The greater the curvature, the shorter the focal length.

For the eye, for all practical purposes, it has been determined that an object 20 feet away from the eye can be considered to be at infinity and the rays falling on the lens parallel. Thus, when we observe an object 20 feet or more away, the parallel rays striking our eyes converge at the focal point of the lens. Placing an object more than 20 feet away has little effect on the focal length of the lens.

In a normal eye, the parallel rays of light traverse the lens and intersect at the principal focus and the image is in focus at the retina.

Experiment 4. Look through your convex lens at an object about six inches away from the lens. Move the lens back and

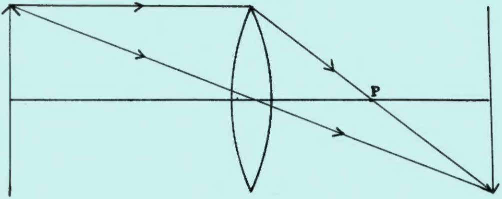


Fig. 3

forth until you reach a position where a clear image of the object is seen. Is it inverted?

The image formed by a convex lens is inverted when the distance of the lens from the object is greater than its focal length (Fig. 3) and is called a real image.

The image formed on the retina of the eye, just as in the image you observed, is inverted. But when we see objects, they do not appear upside down to us. The brain has been trained by experience to interpret messages from the retina properly and we see objects right side up as they are.

Experiment 5. Hold your convex lens about a foot away from the side of a small unshaded lighted light bulb. By using the side of the light bulb you can

see whether the image is right side up or upside down. On the other side of the lens hold up a piece of paper as a background to receive the image. Note that the image is inverted.

Move the paper back and forth slowly until the image is clear and distinct. Observe the image distance. Now have a friend move the lamp a few inches further away from the lens while you hold the lens and background steady. What happens to the image? Do you need to change the distance between the background and the lens to maintain a clear image? Does the image grow larger or smaller?

Now bring the lamp closer to the principal focus. What happens to the image? Does it become larger than the object? Is the image distance increased?

When an object forms an image through a convex lens, the distance of the image from the lens changes as the distance of the object changes, and the further away the object, the smaller the image.

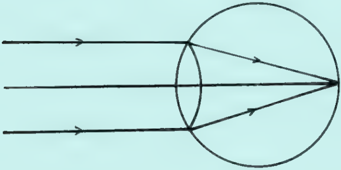
In the eye, the distance between the lens and the retina is fixed. This means that no matter how close or how far away an object being observed is, the image formed on the retina is always the

same distance from the lens.

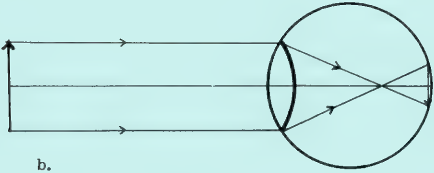
To take care of this situation so that an image will always focus on the retina, the eye is provided with muscles to change the curvature of the lens, lengthening or shortening the focal length as necessary.

This focusing action is called accommodation.

When the normal eye looks at a distant object (any object viewed from a distance



a.



b.

Fig. 4

of 20 feet or more), the lens is relaxed and flattened by the action of the ciliary muscles. The rays entering the eye are parallel and the image is formed at the principal focus (Fig. 4a).

However, when an object is close by, the image will lie beyond the principal focus. The eye, therefore, increases its curvature and thereby reduces its focus length so that the real image will form on the retina (Fig. 4b).

Experiment 6. As mentioned, the part of the retina having the highest visual acuity is the fovea centralis. As you read this page, the eye moves so that the image of each word falls on the fovea. If the image extends outside this tiny spot, it becomes less clear.

Focus your eyes steadily on a single letter on this page and note that the letters around the outer area of this point appear less distinct.

The fovea contains cones only. As the distance from the fovea increases on the retina, the proportion of rods to cones increases and visual acuity decreases. The area far outside the fovea or the peripheral region contains mostly rods and is therefore very sensitive to light and is also highly sensitive to movement.

Experiment 7. With your eyes focused at a point in front of you, hold your hand with fingers widespread at the side of your face near the edge of your visual field. Can you count your fingers? You will find that visual acuity is so low this is not possible.

Now, while still looking straight ahead, make a slight movement with one of your fingers. Note that the movement is readily observed.

This ability to see movement from the sides of the eyes, known as peripheral vision, is very useful and extremely important for safe driving of cars.

The eyes of humans are not always perfect. Many people need the help of glasses to see clearly. There are three main optical defects of the eyes—nearsightedness, farsightedness and astigmatism.

NEARSIGHTEDNESS

Some persons may have eyes that converge the light too much or eyeballs that are too long. When such defects occur, the person is nearsighted.

In a normal eye that is completely relaxed, the light rays that fall on the lens from distant objects are brought to a focus on the retina and these objects ap-

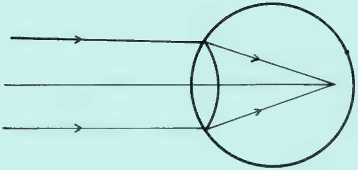


Fig. 5

pear clear and distinct.

However, in the nearsighted eye, the parallel rays come to a focus in front of the retina (Fig. 5) and distant objects looks fuzzy. The focal length, in other words, is too short.

Only when close objects are being observed does the image with the aid of accommodation fall on the retina. So this condition is called nearsightedness, or myopia.

Experiment 8. In your unit, the ½-inch diameter lens is a concave lens. Examine the lens and note its curvature. The lens is hollowed out on each side like a shallow "cave." Concave lenses may also be made with a curvature on one side only.

A concave lens diverges or spreads light rays (Fig. 6) and is referred to as a diverging lens.

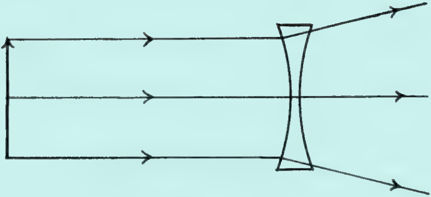


Fig. 6

Mount the concave lens in its lens holder and look through the lens at a nearby object. Is the image right side up or inverted? The image formed by a concave lens is right side up and is called a virtual image (Fig. 7).

Place the lens between the unshaded lamp and the background paper as you did with the convex lens. Do you obtain an image?

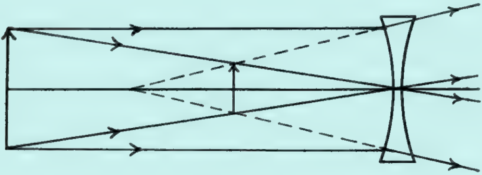


Fig. 7

The principal focus of a concave lens lies between the object and the lens at a point from which the rays parallel to the principal focus seem to diverge as they emerge from the lens (Fig. 7).

The image formed by a concave lens, therefore, is erect but is only apparently there. If you put a photographic film in the plane of this virtual image, no picture would result.

To permit a nearsighted person to see distant objects clearly, glasses that diverge the light rays ars used. Concave lenses of the right curvature will bring the parallel rays to a focus on the retina of a nearsighted eye (Fig. 8).

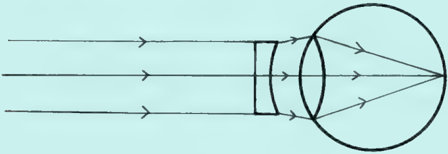


Fig. 8

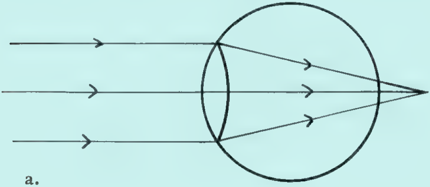
FARSIGHTEDNESS

If the eyeball is too short, the distance from the lens to the retina is decreased. This causes the image of a distant object to fall behind the retina in a relaxed eye.

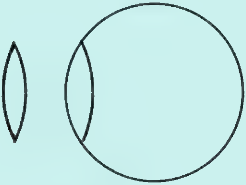
Such a condition is known as hyperopia or farsightedness. An individual with hyperopia, with a little accommodation, can see distant objects clearly, but cannot accommodate sufficiently when viewing nearby objects to produce a clear image.

Hyperopia is corrected by using eyeglasses with convex lens which help bring the images of objects close by to a sharp focus (Figs. 9a and 9b).

As a person grows older, most of his muscles gradually lose their contractive



a.



b.

Fig. 9

power. The same happens with the ciliary muscles. The lens of the eye also loses some of its elasticity. Therefore, after about 45 years of age, the eyes are less able to accommodate. As a result, the rays come to a focus behind the retina when close objects are observed. This condition, known as presbyopia, is also referred to as farsightedness and is corrected with convex lenses.

Usually a farsighted person can see distant objects more clearly than those nearby. Bifocal glasses therefore are a convenience, replacing the need for two pairs of glasses, one for distant and one for close vision.

Experiment 9. Can you illustrate by completing Fig. 9b how a convex lens corrects farsightedness?

ASTIGMATISM

Usually the cornea of the eye is smooth and the cornea and the lens uniformly curved so that the rays from a distance are directed into the center of the retina. However, oftentimes, the curvature of the cornea is irregular and may have a sharper curvature in one plane than in another. The rays of light therefore cannot come to one focal point but are spread out along a line, thus causing blurring of the image

on the retina.

To correct this defect, cylindrical lenses are used. The lenses are made to counteract precisely the defect of the eye lens.

Experiment 10. To test for astigmatism, look at Fig. A on the sheet of diagrams included in this unit.

If your eyes are normal, all lines will appear equally sharp and distinct.

If your eyes are astigmatic, some of the lines will appear darker and more distinct than others, while some may appear blurred.

The lines that appear sharpest will always be at the same angle to the horizontal. You can test this, if you have astigmatism, by rotating the diagram. Why is this so?

PUPILLARY REFLEX

The pupil through which light enters the eye is controlled by the iris. When a room is lighted brightly or a person is in the sunlight, the pupils contract to shut out some of the light rays. If the person then enters a darkened room, his pupils will dilate to allow the maximum amount of light to enter the eyes.

Experiment 11. To observe the contraction of your pupils, stay in a com-

pletely darkened room for at least five minutes. Then while holding a mirror in front of your eyes, turn on a bright light and look closely at your pupils. Do they contract? The same effect will be obtained by stepping out into the bright sunlight.

The pupils also constrict when a near object is viewed to prevent stray light from the object from entering the eyes from the periphery and interfering with visual acuity.

BLIND SPOT

The blind spot, the point at which the optic nerve leaves the eye, can be demonstrated by a simple experiment.

Experiment 12. Cut Fig. B from your sheet of diagrams. Hold it in your left hand and cover up your right eye with the other hand. Fix your left eye on the dot and bring the figure gradually closer and closer to the eye until the triangle disappears. Notice that it vanishes completely. How far from the eye is the figure when the triangle disappears?

Repeat the experiment with your left eye covered and your right eye fixed on the triangular spot.

Draw a similar dot and triangle on a

piece of colored paper. Repeat the experiment. What color is the spot from which the triangle or dot disappeared? Repeat the experiment again using another color or a background with a fine close-knit design.

Note that in each case the background of the blind area is filled in with the same color or essentially the same design of the paper you used.

Observing the position of the dot or triangle that disappears, can you tell the relative position of the blind spot to the fovea?

BINOCULAR VISION

How is it that we have two eyes yet see only one image?

Experiment 13. Hold a pencil about 15 inches in front of the eyes of a friend and ask him to focus his eyes on it. Then move the pencil toward his eyes slowly. Do his eyes turn inward as they follow the object? The eyes converge when looking at a near object to obtain single binocular vision or to see only one object when both eyes are used.

When we look at an object, each eye sees a separate image, but the two are blended into one by the brain. Since the eyes are set slightly apart, each eye has a

slightly different view of an object, the left eye seeing more of the left side and the right eye more of the right side of the object. As a result, the objects we see have depth.

Experiment 14. To demonstrate this focus your eyes on a small object about 15 inches in front of you. Now cover up the right eye and note the position of the object you see just with the left eye. With the eyes still focused on the object, cover up the left eye and observe the object with the right eye. Note that the object seems to move from one side to the other and also that each eye has a slightly different image of it.

When you observe an object with both eyes, it is seen between the two as a mental image (Fig. 10).

Experiment 15. Now fix your eyes on an object about 12 feet away. Hold your index finger in line with your nose and about six inches away from your eyes. Note that you see two fingers, like transparent shadows. Since you are focusing at a distance, each eye sees the finger independently.

While still focusing on the distant object with your finger in the same position, close one eye and then the other. In which

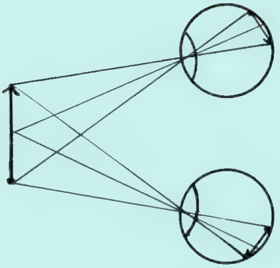


Fig. 10

field of vision does each eye observe the finger?

Experiment 16. Take the black paper in your unit and roll it up to form a tube with a diameter of about one inch. Hold the tube up close against your right eye. Open your left hand and place it against the lower end of the tube so that your palm faces your left eye. Now, keeping both eyes open focus them on a distant wall or the blue sky. Do you see a hole in your left hand? Why?

Experiment 17. Pick up the red paper in your unit with one hand and the blue piece with the other. Hold them side by side with the surfaces facing you about 12 inches in front of your eyes and about

one-fourth inch apart. Look at a distant object through the one-fourth-inch space.

What happens to the images of the two sheets? Note that you now see three pieces of paper instead of two, all apparently at the same distance from your eyes—the red and blue sheets and a mixture of the two colors in between. What happens to the sizes of the sheets?

The eyes, which are conditioned to seeing a single image with two eyes, supply an image in space where there is none.

Note the positions of the three images. Close each eye alternately and observe how the colored squares seem to shift in position. Does the center image disappear with monocular vision?

Experiment 18. Cut out Fig. C from the sheet of diagrams. If you wish you may mount it on a larger stiff paper.

Place the diagram about 20 inches in front of your eyes so that the space between the two circular figures is in line with your nose. Now take a pencil and hold it about 10 inches or so (you will have to adjust this distance to suit your own eyes) in front of your nose and focus your eyes on the tip while still keeping the circles in view.

The eyes while focused on the tip of the pencil are still seeing the circles—the left eye the one on the right and the right eye the one on the left.

As you look at the pencil note that the circles become merged and a central three-dimensional image of the two combined appears between them. The central figure has apparent depth and a stereoscopic effect is produced. This occurs when two figures that are slightly off center and mirror images of each other are placed next to each other and observed in this manner. This principle is used in the old-fashioned stereoscopic viewers.

Binocular vision provides us with the ability to see stereoscopically, or with depth, even making us see two-dimensional objects as if they were three-dimensional.

Can you produce stereoscopic images by drawing two cubes? Converging lines? With a little experimenting you can produce many effects. Include color in some of your pictures.

Experiment 19. Repeat the experiment with Fig. D.

What significant phenomenon appears when the two squares blend?

Note that while the triangle seems to be superimposed on the lines, it appears and

disappears. This is known as image rivalry and occurs when the right and left figures are completely different.

Make various drawings that show this effect. Pictures with lines are most effective.

AFTERIMAGE

Experiment 20. When the object that an eye observes is removed from the line of vision, the image does not disappear instantaneously, but lingers for a few seconds. This image is known as an after-image and is the effect that makes motion pictures possible.

Spots before the eyes after seeing a bright flash of light is an example of after-image.

There are many experiments to demonstrate this phenomenon, a few of which are included here.

Observe the figure of concentric circles on your sheet (Fig. E). Note that with each slight movement of the eyes, the circles seem to turn in one direction or the other. This is the result of after-image.

Experiment 21. Cut out Fig. F into two parts so that you have a picture of the square and the circle on each strip. Paste the two strips back to back over

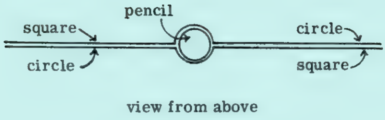


Fig. 11

the end of a long pencil (Fig. 11). Be sure they are glued on securely.

Now look at the pictures while you roll the pencil back and forth between the palms of your hands turning the pictures fairly rapidly, but not too fast. Does the circle appear to be in the center of the square? This effect occurs because each image remains momentarily in your eyes.

Make various drawings of your own to demonstrate afterimage.

Experiment 22. Cut out Fig. H and paste it on a piece of cardboard cut to the same size. Push a straight pin through its center, easing the hole slightly to allow the disk to revolve freely. Insert the pin into the top of a pencil eraser and spin the disk. When it spins rapidly, the short lines form continuous circular lines around the disk. Another afterimage effect.

Experiment 23. Using this disk as a

pattern, cut circles from the colored papers in your unit. Make a small dot at the exact center of each circle with a pencil. Slit each disk to the center point from the outer edge. Fit the red and blue disks into each other so that half of each is visible. Hold them in place with a paper clip or a short length of cellophane tape. Insert a pin through the center with this wheel and mount it on the top of a pencil eraser. Spin the wheel. What colors do you see?

Colors also produce afterimages and blend to produce a new color, a combination of the two.

Change the proportions of the colors, for example one-third red to two-thirds blue. What happens to the colors?

Repeat the experiment using the red and green together. If the colors used are complementary, you will get a light gray effect with the right proportions of each color.

OPTICAL ILLUSION

Among the most interesting of visual effects is optical illusion. In optical illusion we see things as we think they should be rather than as they are, because of our previous experiences. This visual

property is widely applied in our daily lives, in art, design and architecture.

Experiment 24. People can be made to believe things are longer than they are. Observe the figures below (Fig. 12). Which line seems longer? Measure them. They are exactly the same length, but the lines extending outward make one line appear longer.

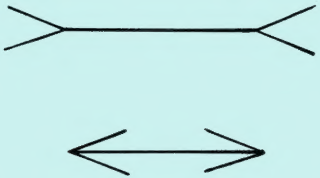


Fig. 12

In Fig. G on the sheet of diagrams which line looks longer? Measure them. Horizontal lines look shorter than vertical lines and wide lines look shorter than thin lines.

Look at Fig. I. As you look at the wheel, note that the lines reverse and become valleys or peaks, because of the directional lines. Does the figure give a sense of depth?

Many examples of optical illusion have been designed. Op art is based on optical

illusion.

Make diagrams of your own that will demonstrate that the eyes do not always see what they seem to see and the mind can deceive the eyes.

Experiment 25. Spin the black and white disk again, but more slowly and note that colors appear along the lines. What colors do you see and where are they located on the wheel? Scientists cannot fully explain this phenomenon. The colors depend upon the length and position of the black lines. Make patterns of your own with both thinner and wider lines and see what patterns of colors you can produce.

There is much more about the physiology and psychology of vision that you can discover by pursuing the subject further. The following references will be helpful.

Physiology textbooks.

Elementary physics textbooks.

Seeing and the Eye, G. Hugh Begbie, Natural History Press, New York.

* * * *

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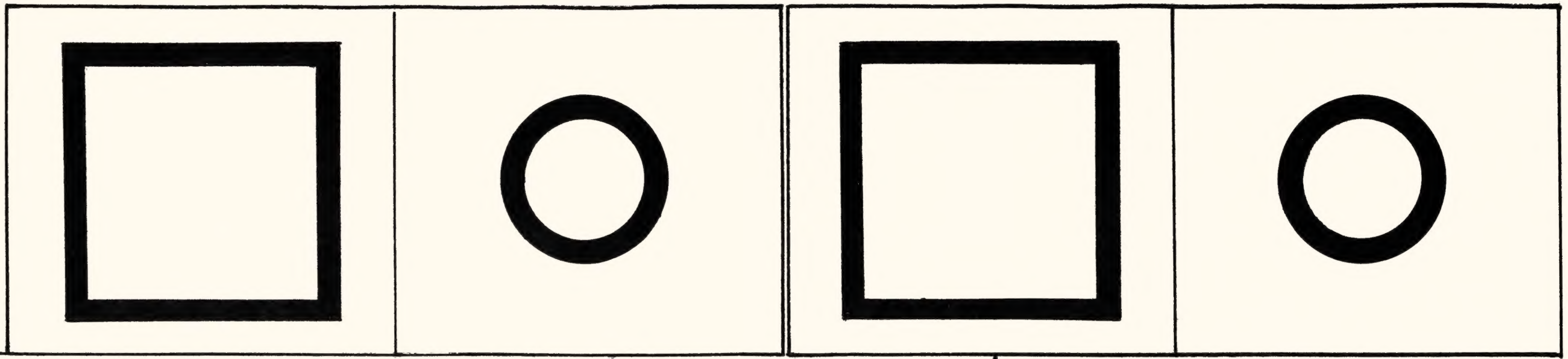
(Add $1.50 for outside U.S.A. addresses.)

Fig. F



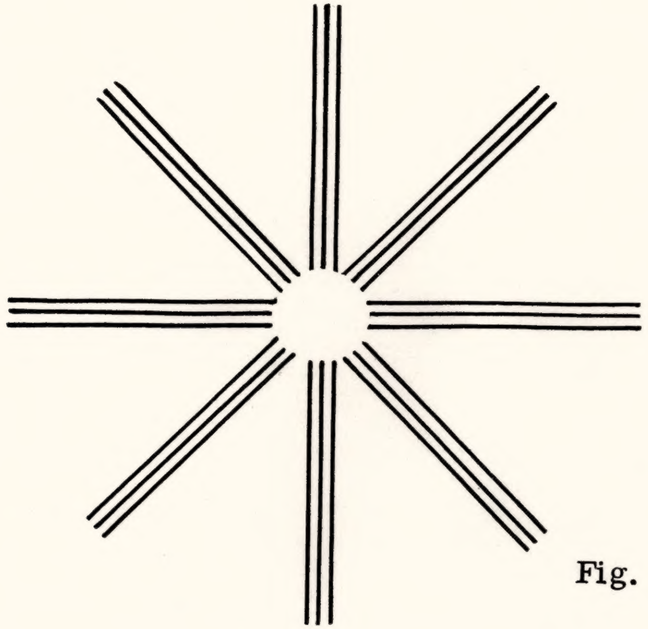


Fig. A

Fig. B

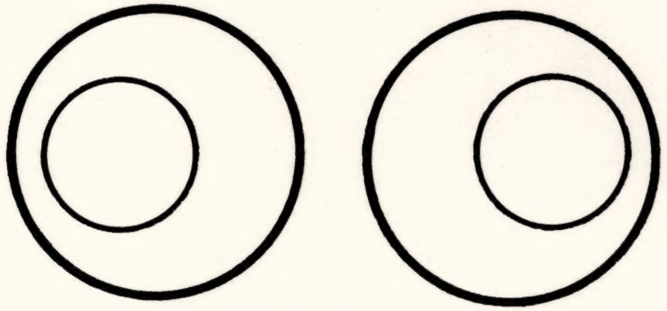


Fig. C

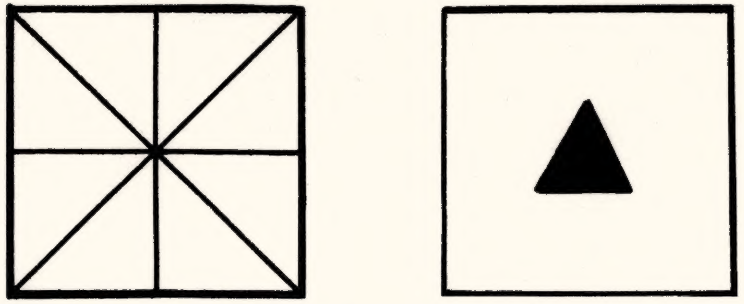


Fig. D

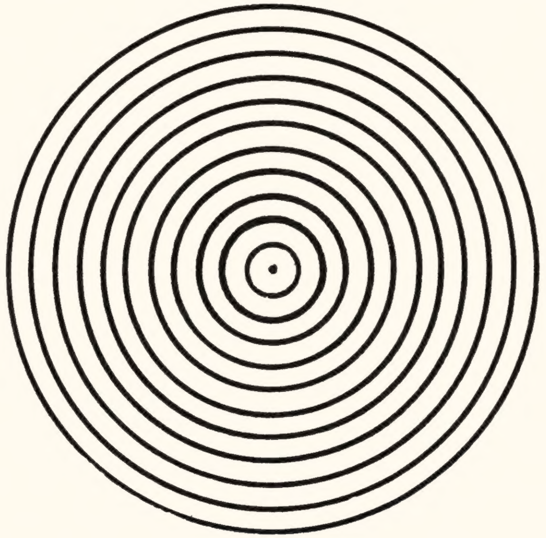


Fig. E

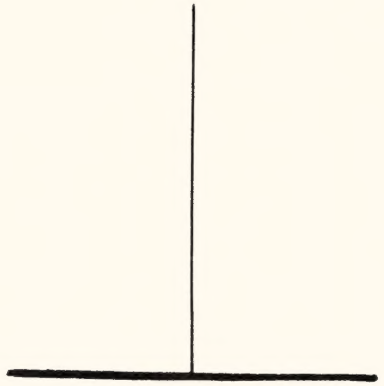


Fig. G

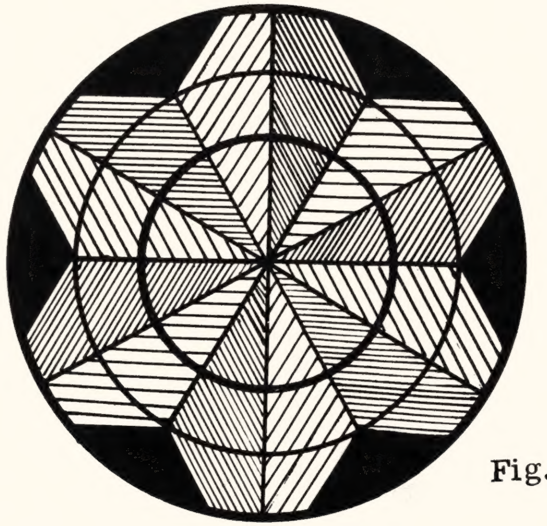


Fig. I

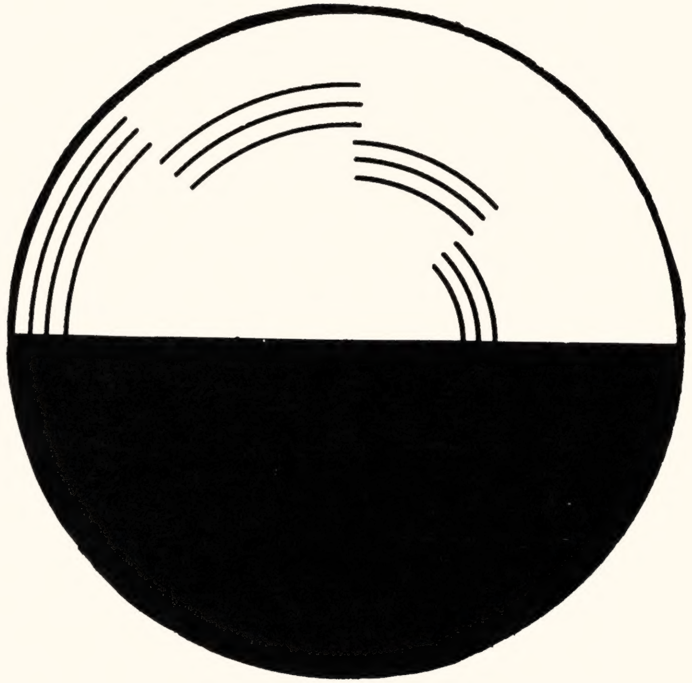


Fig. H